Factors Influencing the Nearshore Sound-Scattering Layer in Hawaiian Waters

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LONG-TERM GOALS

Our long-term goal is to develop the capability to predict the spatial dimmensions and temporal occurance of aggregations of the nearshore sound-scattering layer in the coastal ocean.

OBJECTIVES

Our objectives are

(1) to quantify aggregations of the nearshore sound-scattering layer around Hawaii,

(2) to identify the physical and optical characteristics associated with these aggregations, and use this information

(3) to develop the capability to predict the occurrence of the nearshore scattering layer in Hawaiian waters.

APPROACH

This project takes an interdisciplinary approach in the investigation of the relationships between the nearshore sound-scattering layer, physical processes, the optical properties of the water column, and bathymetry. We combine moored and expeditionary approaches to determine the critical predictors of micronekton distribution.

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WORK COMPLETED

We examined the nearshore sound-scattering layer off the leeward coast of Oahu, this area is known to be a highly productive fishing area (Figure 1). We are currently comparing information on the nearshore component of the micronekton community's migration to physical and optical properties of the water column. The sound-scattering layer first appears 3 km from the shoreline just after dusk. The migration continues inshore, reaching 1 km from the shoreline within an hour and a half. The density of micronekton continues to increase until approximately midnight when the migration reverses. The sound-scattering layer moves offshore, last observed at 3 km from shore just before sunrise.

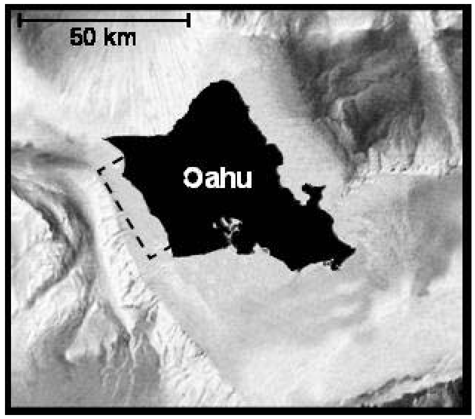

Figure 1: [The sampling area off leeward Oahu is enclosed by dashed lines.]

Mooring Array An array of moored, upward-looking 200 kHz echosounders were deployed between 23 April and 26 May of 2005. These echosounders are being used to characterize the movement of the sound-scattering layer. Three moorings were deployed along the 40 m isobath (Figure 2B, C, D), while a fourth mooring was deployed inshore of the middle mooring on the 26 m isobath (Figure 2A). These moorings recorded 10 echoes every 15 minutes during the night for ~5 weeks. They provided information on the depth and intensity of the sound-scattering layer over time, allowing us to investigate the movement patterns of the layer across the island's slope as well as the variability in the layer within and between nights.

In conjunction with the echosounders, thermistor chains were deployed in the T-shaped array (Figure 2A, B, C, D). The thermistor chains measured temperature at fixed depths throughout the water column, every 30 s. Information from the array of thermistor chains is allowing us to investigate the passage of ocean eddies and fronts, internal tidal energy and vertical water column structure (after McManus et al. 2005 in press).

One autonomous profiler was deployed at the 26 m site (Figure 2A). The autonomous profiler (the Seahorse; Brooke Ocean Technology) uses wave energy to power extended, high-resolution profiling of water properties. The instrument was moored to the seafloor and is left to collect samples autonomously. A SeaBird SBE-19 CTD on the profiler measured temperature, salinity, pressure, and oxygen. A WET Labs Inc. ECO-FLS fluorometer on the profiler measured chlorophyll fluorescence. The fluorescence values were converted to chlorophyll a, which is a bulk measurement of phytoplankton biomass. The autonomous profiler provided hourly measurements of phytoplankton biomass, throughout the entire water column over ~5 weeks. While micronekton in the nearshore

sound-scattering layer are not feeding directly on phytoplankton, they are feeding on smaller zooplankton, which in turn feed on phytoplankton. We are investigating the positive and negative correlations between the trophic links in the nearshore food web, which may provide clues about the ultimate factors driving the patterns we see in the nearshore sound-scattering layer. High-resolution vertical profiles were collected hourly between the bottom and the surface at ascent rates of 5 - 7 cm s^{-1}. Between profiles, the sensor package was held stationary at the bottom until the next sampling interval. Information from the autonomous profiler is allowing us to investigate the passage of ocean eddies and fronts, changes in tidal energy, fine scale, vertical water column structure, Thorpe displacement scales (Thorpe 1977) and heat loss/gain.

Previous attempts to utilize an acoustic Doppler current profiler (ADCP) during the layer's migration have had limited success because of high scattering from the rapidly moving mesopelagic micronekton (Benoit-Bird et al. 2001). Consequently, in the past only currents between mesopelagic patches or above the mesopelagic layer could be measured. Thus, Nortek current meters were deployed at the mean depth of the scattering layer on two of the thermistor chains (Figure 2B, D). Each Nortek current meter measured current speed and direction at 2 min resolution. Due to the generosity of the staff at the Ko'Olina Harbor, we were allowed to link into their weather station, which was in direct alignment with the array. The weather station measured local wind magnitude and direction, as well as air temperature and barometric pressure every 15 minutes. Information from the weather station is allowing us to investigate wind driven flow and heat loss/gain in the system. Finally, a bottom-mounted ADCP was deployed at the center of the array (Figure 2C) to observe full water column current patterns at least when the scattering layer was absent.

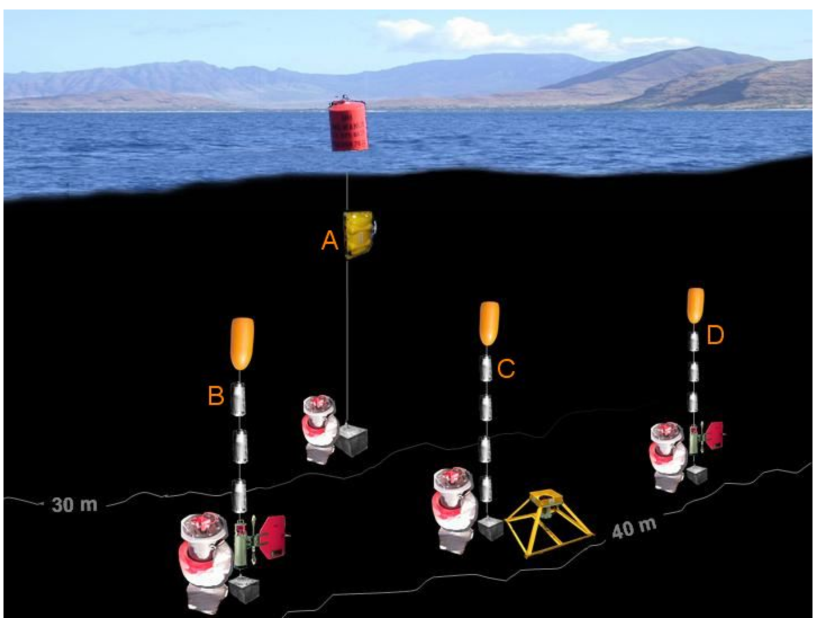

Figure 2. [Schematic of mooring array. (A) 200 kHz echosounder, autonomous profiler (the Seahorse; Brooke Ocean Technology), (B) 200 kHz echosounder, thermistor chain with 3 temperature units. (C) 200 kHz echosounder, thermistor chain with 4 temperature units, bottom mounted ADCP. (D) 200 kHz echosounder, thermistor chain with 3 temperature units. Figure created by Dr. Benoit-Bird. Please note: isobaths trend in a NNW – SSE direction].

Ship Board Surveys To further characterize the location of the sound-scattering layer, hydrography and optical properties in 3-dimmensions, we will utilized a small vessel (31 ft) to conduct ship surveys. Three, 3-d ship surveys (2 on the spring tide and 1 on the neap tide) were undertaken during the ~5 week long mooring deployment. Our shipboard profiler was equipped with

(1) a low-light camera system to identify micronekton and estimate its size and the numerical density of animals,

(2) a WET Labs Inc. ac-9 to measure total absorption and attenuation of light at nine wavelengths between 412 and 715 nm,

(3) a SBE 25 CTD to determine conductivity, temperature, and depth, and

(4) a PAR sensor to detect photosynthetically active radiation.

These profiles provide a spatial rendering of the micronekton distribution, spectral absorption and attenuation and hydrography. Spectral absorption at 440 nm is being used to quantify fine scale optical structure. Absorption at this wavelength is an inherent optical property dominated by phytoplankton chlorophyll a absorption. Thus, the profiler provides a 3-dimmensional spatial picture of phytoplankton biomass distribution during three cruises. This information provides important data on potential differences in phytoplankton biomass between the northern and southern regions of our sampling area where differences have been observed in the scattering layer. Split-beam scientific echosounders operating at 38, 70, 120, 200, and 400 kHz (Simrad EK 60s) were used to map the distribution of acoustic scattering layers. Surveys of the horizontal and vertical distribution of sonically scattering organisms were conducted around the array at a vessel speed of 3 m/s. A downward looking 600 kHz ADCP was also used in conjunction with the echosounders. This data is being compared with the results from the moorings to determine how predictable patches within the sound-scattering layer are and if patches are correlated with specific locations.

2006 Survey: Our second survey will occur between 23 April and 4 June 2006. During this mooring deployment we will also conduct shipboard surveys on 3, 3 daylong cruises. These cruises will target 2 spring tides and one neap tide.

RESULTS

The Physical Environment

General Current Patterns: The currents in our study area were primarily along-isobath. Current speeds measured in the water column ranged from 0.01 m/sec to 0.40 m/sec, with a mean of 0.15 m/s. The along-isobath current speeds were typically an order of magnitude larger than the across-isobath current speeds. Oscillatory tidal flows enhance these mean flow speeds (Figure 3).

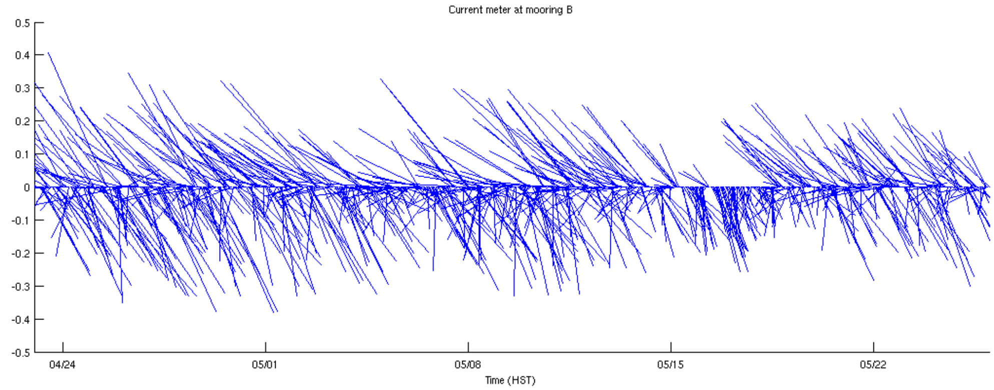

Figure 3. [Vectors of current magnitude and direction from a Nortek current meter deployed at mooring site B between 23 April and 26 May 2005.]

Temperature*:* Measurements of temperature from Mooring A are presented in Figure 4. Temperature varied signficiantly over the 31 day sampling period. Between 23 and 27 April, the water was relatively cool (24.6 – 25.4 ^{o}C) and stratified. A warmer water mass (25.4 – 26.2 ^{o}C) moved into the sytem between 4 and 15 May. During this time, the stratification was weaker. At the end of the study, between 15 and 24 May, stratification increased and overall water temperatures dropped an average of 1 ^{o}C.

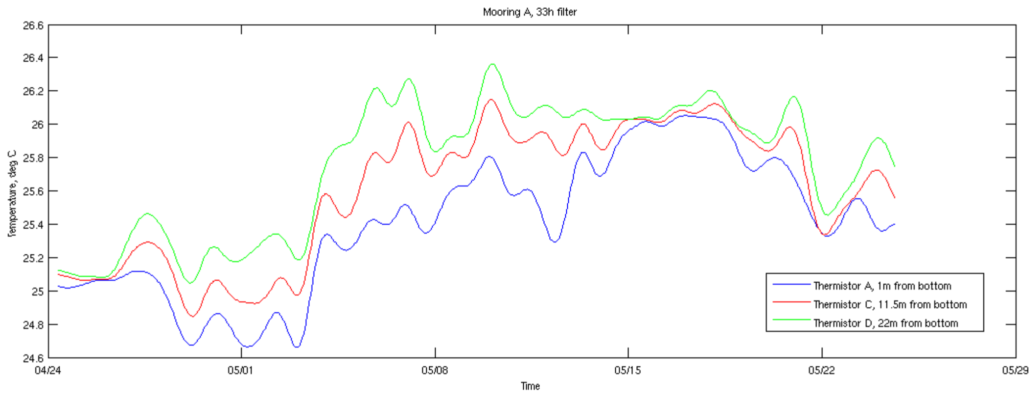

Figure 4. [Measurements of temperature at 1, 11.5 and 22 m above the bottom, beteween 23 April and 24 May, from Mooring A. A 33-hour filter was applied to remove the strong fluctuations in temperature due to tidal forcing.]

Oxygen: Hourly profiles of Temperature, Salinity, pressure, O_2 and fluorescence were made with an autonomous profiler (the Sea Horse). Oxygen values between the surface and 6 – 8 m in depth were elevated for the entire study(Figure 5). Periodic increases/decreases in oxygen levels near bottom, are being compared to the onshore movement of micronekton.

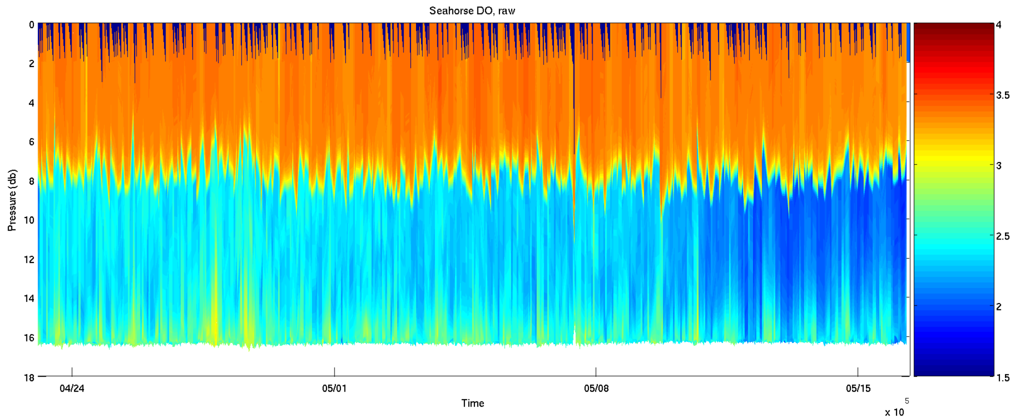

Figure 5. [Hourly profiles of Oxygen from the bottom to the surface made with a DO sensor on the Sea Horse.]

The Nearshore Scattering Layer

Increased zooplankton abundance is first observed inshore (1.5 and 3 km from shore) at 2100 hours. At midnight a strong across-shore gradient in zooplankton abundance is evident; 20 mg m^{-3} 5 to 7 km offshore, 40 mg m^{-3} 3 km offshore, and up to 100 mg m^{-3} 1.5 km offshore). An example of organisms sampled is given in Figure 6.

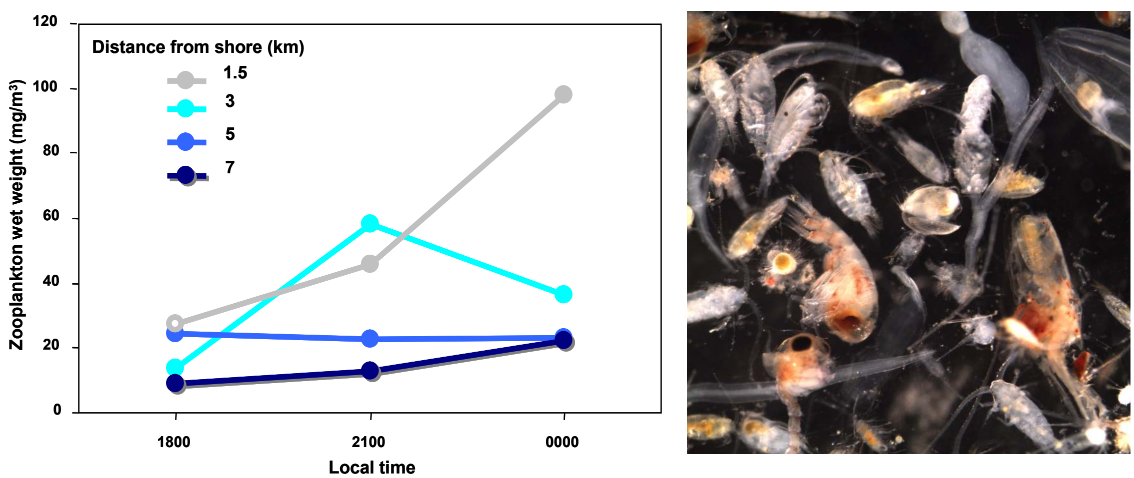

Figure 6 [A. Zooplankton wet weight mg m^{-3} from 1800 to 2400 hours, at 1.5, 3, 5 and 7 km offshore B. Organisms sampled in the nearshore scattering layer, off the west shores of Oahu]

A representative profile of phytoplankton and zooplankton vertical distribution, a 3-minute time series of micronekton sampling and a representative profile of dissolved oxygen are given in Figure 7. Distinctive thin layers of both phytoplankton and zooplankton are observed in the system. Depleted oxygen occurs at the edge of micronekton layer.

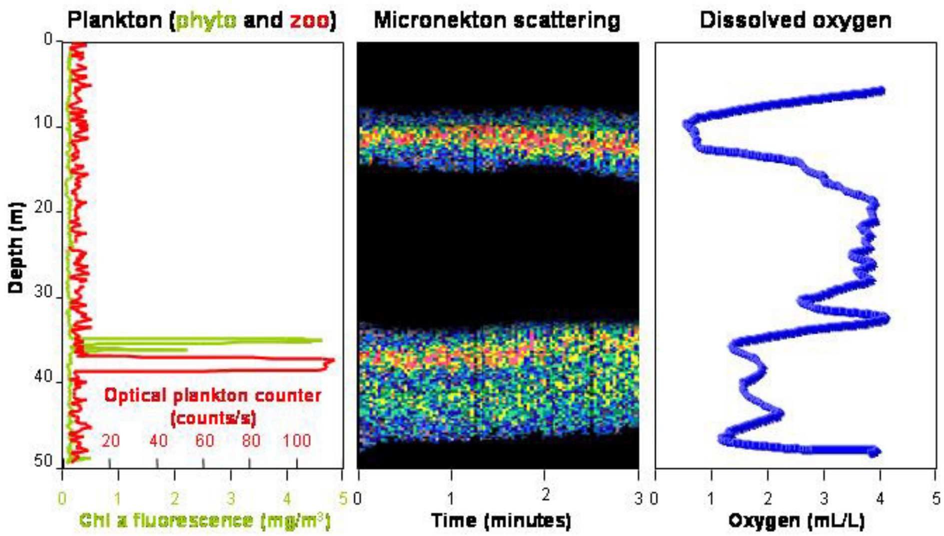

Figure 7.[A profile of from the WetStar (Chl a) and the optical plankton counter (zooplankton), a 3-minute time series of micronekton scattering and a representative profile of dissolved oxygen (mL/L)]

Thin Layers: Although we did not set out to measure thin layers in this study, we observed intense, persistent thin layers in both the optics and the acoustics data. A 24 day time series of relative fluorescence from the SeaHorse is given in Figure 8. There are 576 continuous profiles in this record, with < 1 cm vertical resolution. A thin optical layer was observed for the majority of the experiment. Near the end of the experiment (~12/13 May), the fluorescence sensor fouled, resulting in an overall increase in the measured relative fluorescence values. We are trying several different techniques to remove this signal. We observed very strong micronekton aggregation at near optical thin layers.

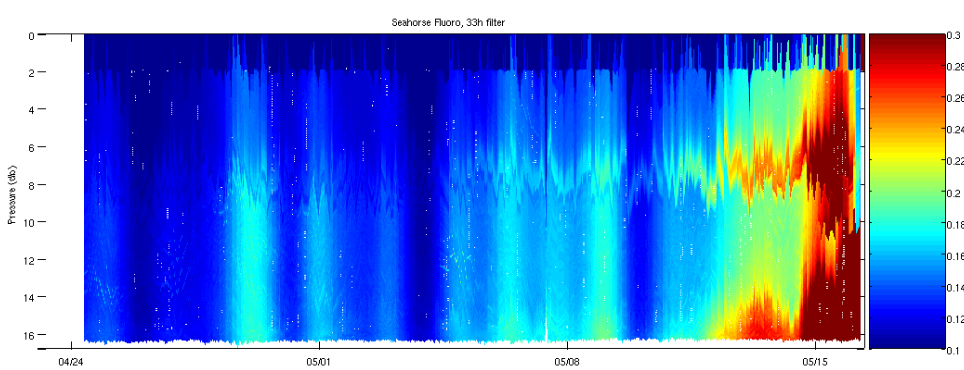

Figure 8. [A 24-day time series of relative fluorescence from the SeaHorse. A 33-hour filter was applied to this record to remove tidal variation.]

IMPACT/APPLICATIONS

This research combines work in acoustics, optics and physical oceanography to understand the distribution of mesopelagic animal biomass. We address the relationship between this significant biological source of scattering and the acoustical, optical, and physical characteristics of the water column. Our goal is to determine if simple, physical and/or optical measures can be used to make predictions about the distribution of scatterers. The ability to predict biological sources of scattering will provide significant information for the interpretation of tactical acoustic and optical instruments. Prediction of the scattering layer may have significant implications for understanding local fisheries, as commercially important species including tunas, billfish, and deepwater snappers rely on these micronektonic animals as a significant food resource.

RELATED PROJECTS

Related projects funded by the ONR DRI LOCO include:

(1) Kelly J. Benoit-Bird (OSU): "Predator Effects on Dense Zooplankton Aggregations in the Coastal Ocean"

(2) Margaret A. McManus "Quantification of the Interacting Physical, Biological, Optical and Chemical
Properties of Thin Layers in the Sea"

(3) D. Van Holliday & Charles F. Greenlaw (BAE Systems): "Layered Organization in the Coastal Ocean: Acoustical Data, Acquisition, Analyses and Synthesis",

(4) Percy L. Donaghay & James M. Sullivan (URI): "Layered Organization in the Coastal Ocean: 4-D Assessment of Thin Layer Structure, Dynamics and Impacts",

(5) Timothy J. Cowles (OSU): "Finescale Planktonic Vertical Structure: Horizontal Extent and the Controlling Physical Processes",

(6) Jan E.B. Rines (URI): "LOCO: Characterization of Phytoplankton in Thin Optical Layers",

(7) David M. Fratantoni & Nelson G. Hogg (WHOI): "The Physical Context for Thin Layers in the Coastal Ocean",

(8) Louis Goodman (U Mass Dartmouth): "AUV Turbulence Measurements in the LOCO Field Experiments", and

(9) Alfred K. Hanson (URI): "An Investigation of the Role of Nutrient Gradients in the Episodic Formation, Maintenance and Decay of Thin Plankton Layers in Coastal Waters".

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**Please note McManus formerly Dekshenieks*